INTEGRATED WETLAND-BIOFUEL CELL FOR SEAFOOD EFFLUENT MANAGEMENT

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ABSTRACT

The increasing industrialization has led to environmental pollution due to high quantity of emission of effluents to the natural resources. The main purpose of this research effort is to develop a waste treatment method for seafood industries waste management and also to produce electricity by introducing a developing technology i.e., constructed wetland coupled with a biofuel cell. Constructed wetlands are engineered systems mimicking natural wetlands for wastewater treatment. They utilize water, aquatic plants (like water hyacinth), native microorganisms, and filter beds (sand, soil, or gravel). Biofuel cells, a rapidly growing green technology, harness microorganisms to convert the chemical energy in organic matter into electricity while simultaneously treating wastewater. This paper focused on characterizing the influent from seafood processing. Various tests were conducted on the effluent before and after treatment with the constructed wetland-biofuel cell system. These tests analyzed factors like pH, alkalinity, hardness, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and conductivity. The Seafood effluent treatment proposed using this technology highly minimize the operational cost, energy utilisation and reduction in effluent discharges with high organic concentrations into the natural resources. Post the treatments the effluents can be released directly into natural resources or can be used for gardening, agriculture, planting etc.

Keywords: Constructed wetland-biofuel cell system, Seafood effluent.

1.INTRODUCTION

The fishing and aquaculture sectors offer jobs to millions worldwide, from small-scale inland fishermen who collect from ponds, rivers, lakes, and marshes to workers in large-scale processing factories. Modern technology has introduced fundamental changes to the public fishing and seafood processing industries. This particular growth has created additional employment opportunities in various related sectors like processing, packing, manufacturing processing equipment, ice making, marketing, distribution, construction, maintenance, research, and administration. Therefore, instead of aiding the underprivileged, businessmen are now more eager to enter the industry. At the same time, rapid expansion of many food sectors has complicated waste management and disposal, and the seafood processing industry is no exception in this regard. Kochi, a major port in Southern India, is a lifeline for large quantities of fish that reach trade markets; numerous large fish-related industries exist in the region. Kerala is endowed with numerous processing units, particularly those related to shrimp

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processing, which require facilities for entire pre-processing and preparation. An adverse effect of the marine industry is the generation of waste, which threatens the environment as well as local livelihoods. The waste has been found to be dumped untreated or poorly treated into adjacent canals or backwaters, thus degrading coastal waters and local drinking water sources. Researchers and business executives are working to discover sustainable ways to manage these environmental effects. There is an urgent need for an eco-friendly and cost-effective solution to treat the effluent discharged by seafood processing. In this respect, possibly a constructed wetland and biofuel cell combination is an attractive alternative for cost-effective treatment of seafood effluent.

Panneerselvam and Priya [1] verified the phytoremediation potential of *Eichhornia crassipes* (water hyacinth) for the remediation of water contaminated with chromium and lead. The results indicated better efficiencies during the 7-day experimentation by water hyacinth in the removal of pH, BOD, COD, TDS, chromium, and lead concentrations. The water hyacinth application in the treatment of industrial effluents was an interesting innovation from their research. The study included different concentrations of water hyacinth, that is, 10% and 20%, with 20% being selected as the best concentration for effective treatment. Lawan et al. [2] examined the treatment of fat, oil, and grease (FOG) trap effluent through a built-in sediment microbial fuel cell (SMFC). Certain enhancements were introduced into the SMFC system to optimize single-chamber SMFCs for effective treatment, namely anode and cathode chamber modifications, selection of electrode materials, and scaling up of the chamber dimension. The research was aimed at making a comparison of the relevant performance indicators like COD removal efficiency, power density, and conversion efficiency of electrical energy against the theoretical chemical energy obtainable from the FOG trap effluent. The biochar addition in the anode chamber was shown to reduce the electrical resistance by 5.76-times. The design of this SMFC configuration was confirmed in favour by reaching COD removal efficiency of about 85.80% within 30 days. Singh and Balomajumder [3] had worked upon the suitability of water hyacinth in the simultaneous elimination of phenol and cyanide from aqueous streams in batch systems, partly in mono and partly in binary component systems. Water hyacinth was grown in aqueous solutions with different concentrations of phenol and cyanide at the ratio of 100:10 to 1000:100 mg/L. A phenol-to-cyanide ratio of 10:1 was used in the study. The effects of varied process parameters such as initial concentrations of pollutants and pH were studied. The results of the investigation demonstrated that the plant could remove phenol up to 96.42 % (at 300 mg/L) and cyanide up to 92.66 % (at 30 mg/L) over 13 days at pH 8. A review was prepared by Ting et al. [4], which provided a detailed account of the technical merits and demerits of phytoremediation compared to other technologies for nitrogen removal and gave directions on the development of phytoremediation systems employing the use of water hyacinth for treating wastewaters high in ammonium nitrogen (AN). Their work also included some introductory considerations to AN removal mechanisms and other determinants to take into account when selecting operating conditions to use in water hyacinth-based phytoremediation systems. Patil et al. [5] studied the efficiency of using the constructed wetland system for wastewater treatment containing *Eichhornia crassipes* (water hyacinth). The work showed that the system was capable of contaminant removal with water hyacinth resilient in high nutrient concentrations and considerable nutrient removals. Qin et al. [6] examined the efficiency of two aquatic plants-water hyacinth and water lettuce-as phytoremediators for nutrient (nitrogen and phosphorus) removal and algal control from a small pond that had been contaminated by domestic sewage (approximately 10,500 m^2 area and average depth of 2.5 m) under experimental setups designed specifically for this purpose. The study dealt with the physicochemical properties of the water and plant samples for the nitrogen and phosphorus mass balance taking place in the entire phytoremediation process. Water hyacinth, with a much higher nitrogen accumulation capability (58.64% of total reductions), was found to be more effective than water lettuce in the intensive treatment of nitrogen-rich domestic sewage. The use of water hyacinth for the removal of pollutants in the wastewater system was reviewed by Rezania et al. [7]. According to the study, water hyacinths absorb nutrient elements for phytoremediation and thereby need to be further managed with some control measures. The study also mentioned substances produced from water hyacinth as valuable by-products. Thus, while invasive plants are useful for wastewater treatment, they may also be harnessed for their sustainability. Physicochemical parameters like pH greatly influence the self-purification process of water bodies while also contributing to the phenomena of eutrophication. Therefore, they determine how the water bodies resist change in acidity or alkalinity (buffering capacity) while contributing towards the solubility and availability of nutrients such as phosphorus and nitrogen in water, which are highly beneficial for the growth of aquatic plants and algae.

The present study aims at developing an eco-friendly and economically feasible waste water treatment solution. The inherent characteristics of sea food wastes are studied, and various tests are conducted before and after the treatment of seafood effluents with constructed wetland coupled with biofuel cells. This current study will contribute to expanding the knowledge and understanding of the utilization of constructed wetland coupled with biofuel cells in sea food effluent treatment, paving the way for sustainable waste management practices and innovative applications of waste generated from the sea food industry.

2.EXPERIMENTAL METHODOLOGY

2.1. Wastewater source and characterization: The seafood effluent was acquired from a seafood industry near Thoppumpady,Kerala,India. Presently, no treatment was provided for the wastewater, and it was directly discharged to water resources located near the industry. The seafood processing industry sources its raw materials from landing centres, including those located outside the state. These materials are subsequently subjected to peeling, cleaning, grading, and are then supplied to processing facilities for further processing and eventual export. Effluent from the industry were collected continuously for 5 days at regular intervals due to large variations in concentration. The effluents were collected in glass bottle and covered with materials that was not transparent. Then placed the covered bottle in rectangular boxes and refrigerated after collection to use for the experiment. The sample was transported to the lab and stored for additional examination at 4°C. The various physico-chemical characteristics of the wastewater were analysed using standard methods. The 5-day Biological Oxygen Demand (BOD) to Chemical Oxygen Demand (COD) ratio for the raw sample was measured at 0.346, signifying the wastewater's predominantly non-biodegradable nature and the potential presence of chemical compounds that could impede biological treatment processes over time. In order to increase biodegradability, a proper wastewater treatment system is essential. Prior to conducting the experiments, a comprehensive physico-chemical analysis of the wastewater was performed in the laboratory. Waste water was analysed for pH, hardness, alkalinity, colour and odour, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and electrical conductivity. Conductivity during preliminary analysis was obtained as 2100µS/cm. The test limit is as per BIS/Guidelines for Quality of Irrigation Water IS 11624 (1986) [8]. The preliminary test results are shown in Table 1.

Table 1. Physico-chemical characteristics of industrial waste water before treatment

Sl. No.	Test conducted	Before treatment	Limit as per BIS/Guidelines for quality of irrigation water IS 11624 (1986) [8] ACCEPTABLE LIMIT
1	pH	6.79	6.5-8.5
2	ALKALINITY (mg/L)	930	200
3	HARDNESS (mg/L)	405	200
4	BOD (mg/L)	623	100
5	COD (mg/L)	1800	250

2.2. Collection of Macrophytes: Water hyacinth was harvested from a pond close to Kalamassery, Ernakulam. It was then collected on that very day to take to the laboratory for setting up the experiment setup. The plants were well washed with tap water followed by distilled water to avoid contamination. Water hyacinth (*Eichhornia crassipes*), a free-floating aquatic plant, is used for the treatment of wastewater on artificial wetlands. Due to its unique ability to absorb nutrients and other substances from water, pollution levels are decreased in wastewater treatment. The roots of the water hyacinth actively assist in treating wastewater. The presence of household wastewater did not affect the morphology of the plants. Aquatic macrophytes in the phytoremediation of industrial wastewater are gaining popularity due to their cheap and energy-friendly treatment. One of the highly efficient ways of treating municipal wastewater and industrial effluents is phytoremediation. The use of water hyacinth proves to be an efficient way to remediate industrial effluents.

2.3. Constructed Wetland Coupled with Biofuel Cell (CW-MFC): CW-MFC is a water pollution management system that has the advantages of both constructed wetland and bio fuel cells. After receiving wastewater, the CW-MFC discharges the effluent into an area where plants offer aeration. The advantage of the CW-MFC system is that it combines the benefits of MFC and CW to simultaneously produce bioenergy and clean wastewater. Plant roots at the cathode release oxygen through the rhizosphere, increasing the efficiency of CW-MFC. The organic material not used during photosynthesis by the plant is then generally converted to electrons and protons by the microorganisms that inhabit the roots. This in turn generates electric current. Additionally, through biomass production via photosynthesis, the plants used in CW also reduce CO_2 emissions. This is one of the ways in which one can produce alternative energy without polluting the environment.

2.4. Experimental Setup: Before entering the main treatment system, usually during peak processing time, which is late morning, cleaned bottles containing shrimp pre-processing effluent were collected from the sea food sector. The experiments were carried out at Albertian Institute of Science and Technology,Kalamassery,Kochi,Kerala,India. Continuous aeration was given to prevent anaerobic conditions. After aeration, the sample was collected, and its physicochemical characteristics were examined. Four rectangular basins of size 40cmx28cmx8cm served as the bed for the root zone treatment in the experimental setup. Aggregates with a size of 20 mm filled the basin's bottom layer. Water hyacinth was placed above this layer with the waste water (Figure 1). The waste water flow through the constructed wetland. Zinc anode and carbon cathode, which were extracted from batteries, were placed in the basin in such a way that the circuit was closed and the voltage was analysed using a multimeter. The electricity produced can be stored and converted for future use.

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Figure 1. Experimental setup

3.RESULTS AND DISCUSSIONS

3.1. Effect of pH: pH is among the most important parameters for indicating the contamination of a wastewater body or the need for pH adjustment in biological wastewater treatment. The bacteria in the sample are in charge of preserving its pH level. Extreme pH, either high or low, renders wastewater unsuitable for sustaining aquatic life. In doing so, it reduces the efficiency of wastewater treatment plants. The study examined the effectiveness of wastewater treatment throughout a pH range of 5 to 8 in order to evaluate the impact of pH on the degradation of industrial wastewater. The optimal level of pH established under the given experimental conditions was 7.02. The ideal pH range to support contaminant removal is between 6.5 and 8.5, as stated by Alemu et al. [9], and the result obtained in this study fall within these limits (Figure 2).

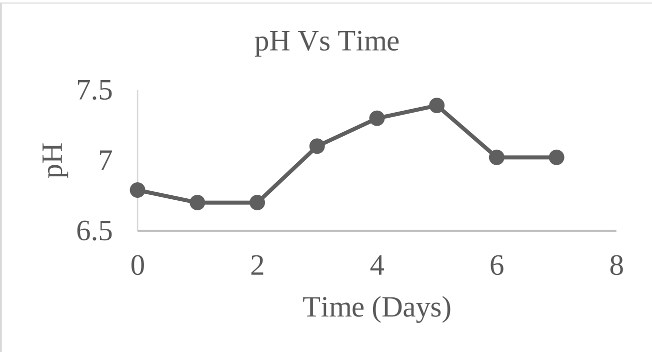

Figure 2. Variation of pH with respect to Time (Days)

3.2. Effect of Alkalinity: Alkalinity is a major parameter in the untreated water chemistry that governs its stability and ability to resist changes in acidity. Total alkalinity in natural waters is generally ascribed to the carbonate and bicarbonate ions. The processing waste, with an intense content of organic matter, has elevated carbonate and bicarbonate values, thereby affecting alkalinity values. Alkalinity helps in maintaining a stable pH environment, which guarantees that the water's parameters stay within a range that is appropriate for their physiological functions. An optimum value of 192 mg/L was observed, which was below the permissible limit of 200 mg/L under the given environmental settings. Ramchandra et al. [10] claim that as water flows through the constructed wetland, the alkalinity value significantly decreases towards the optimum range, which can be seen below (Figure 3).

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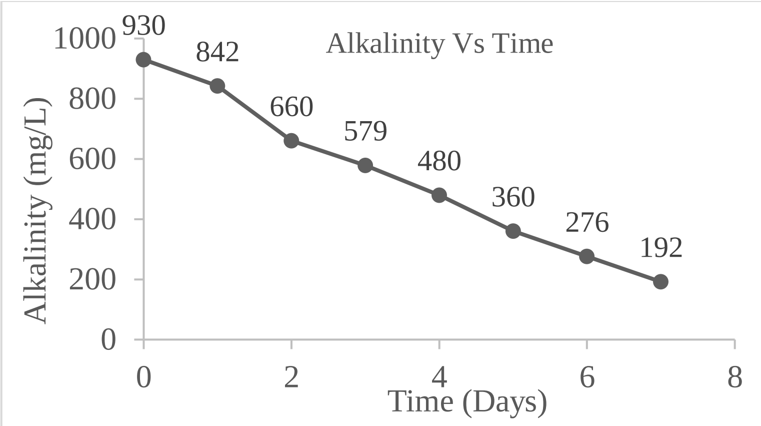

Figure 3. Variation of Alkalinity (mg/L) with respect to Time (Days)

3.3. Colour and odour: The colour and odour of untreated and treated water are key quality parameters, which consequently relate to its suitability for various uses. The effluent discharged by the shrimp pre-processing industry appeared light greyish and had more turbidity, thus confirming the presence of contaminants such as organic matter, industrial waste, and microbial action. This may be due to the fact that less water is used while peeling, and these effluents have a foul and obnoxious odour. Following treatment, the colour of the effluent appeared to be clear, transparent, agreeable, and free from odour. Similar observations were made by Ajayi and Ogunbayo [11], where an improvement in the colour and odour of the effluent after treatment with water hyacinth was reported in agreement with this study. Clear, colourless water with minimal odour indicates successful removal of pollutants to the point of making it safe for human consumption or release into the environment.

3.4. Effect of Hardness: The presence of hardness indicates the hard nature of the sample. Throughout the study period, the higher hardness concentration might be due to the presence of dissolved ions like calcium and magnesium from the groundwater source used in the seafood processing plant. An optimum value of 157 mg/L (Figure 4) resulted due to the uptake by the water hyacinth, thereby reducing the concentration of hardness-causing minerals in the water column. The very dense network of roots and root hairs provides water hyacinth with a large surface area for filtration. While these roots allow the water to pass through, ions contributing to hardness are being absorbed by the plant. By taking up these ions, water hyacinths contribute significantly to lowering the hardness of water.

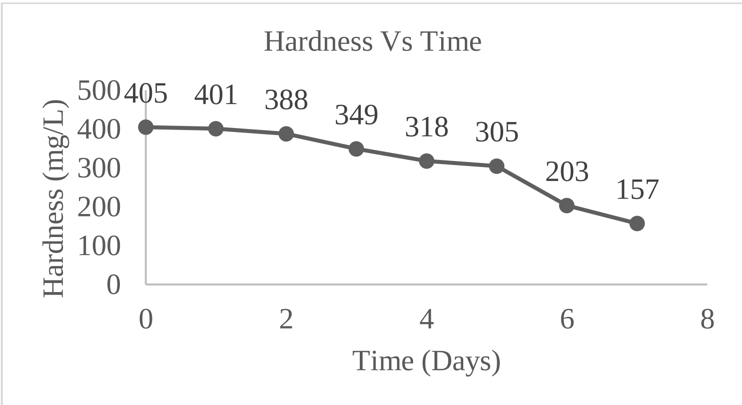

Figure 4. Variation of Hardness (mg/L) with respect to Time (Days)

3.5. Effect of Biochemical Oxygen Demand (BOD): BOD is a key indicator for assessing the extend of pollution in waste water. It quantifies the amount of dissolved oxygen that aerobic microorganisms need to decompose the organic matter in water over a defined period, typically five days. High BOD levels indicate a large amount of organic pollutants, such as sewage or

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agricultural runoff, which deplete oxygen levels leading to disruption of the entire ecosystem. The wastewater was analysed for Biological Oxygen Demand over 5 days. An optimum value of 97 mg/L was obtained. Through a process called rhizodeposition, water hyacinths release oxygen into the water from their roots creating aerobic conditions around the roots thereby promoting the growth of aerobic bacteria which break down complex chemical compounds into simpler, less hazardous substances. It has been confirmed that using water hyacinth as a part of wetland system can substantially decrease BOD in different kinds of wastewater [1], [10], [12], [13]. A significant reduction in the BOD value is evident below (Figure 5).

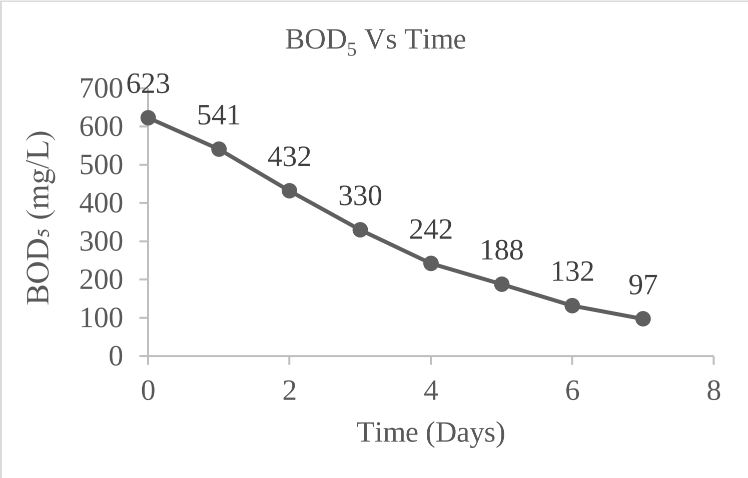

Figure 5. Variation of BOD_5 (mg/L) with respect to Time (Days)

3.6. Effect of Chemical Oxygen Demand (COD): The quantity of oxygen needed to chemically oxidize both organic and inorganic materials in water is known as the Chemical Oxygen Demand which measures the total concentration of organic compounds in water, both biodegradable and non-biodegradable. Elevated COD levels indicate greater levels of oxidizable organic matter and consequently, a lower amount of Dissolved Oxygen (DO). An optimum value of 233 mg/L was recorded (Figure 6). The dense mat-like structure formed by water hyacinths on the water surface contribute shade and reduces the penetration of sunlight into the water. This reduction in sunlight limits the growth of algae and other aquatic plants that compete for nutrients and oxygen with other organisms. Ebrahimi et al. [14] found that CW-MFC demonstrated a higher COD removal efficiency than CW, with a range of 75–99.5% in the compared studies and concluded that CW-MFC could enhance COD removal by up to 22% compared to standalone CW. The COD removal efficiency achieved in the current study is around 87.12%.

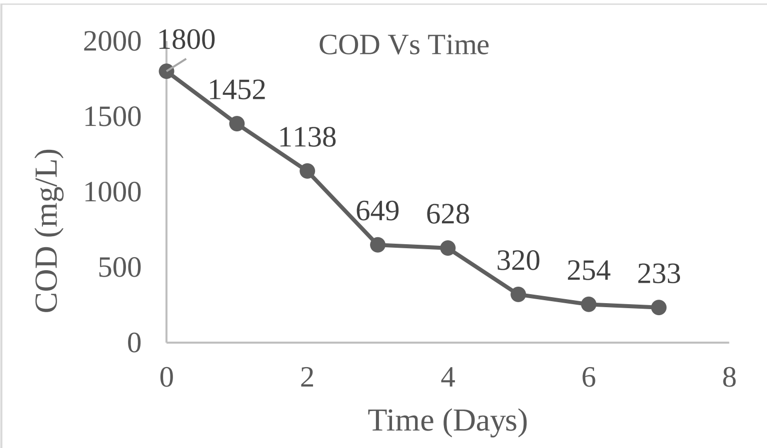

Figure 6. Variation of COD (mg/L) with respect to Time (Days)

3.7. Conductivity: Conductivity in waste water is mainly due to biological nitrogen content, dissolved salts and other inorganic compounds present in it. Conductivity during preliminary analysis was obtained as 2100µS/cm. An optimum value of 1350µS/cm was obtained (Figure 7). Water hyacinths encourage the formation of microbial communities which aid in the biodegradation and additional elimination of organic contaminants, which can obliquely reduce conductivity by getting rid of chemicals and organic ions that increase conductivity overall.

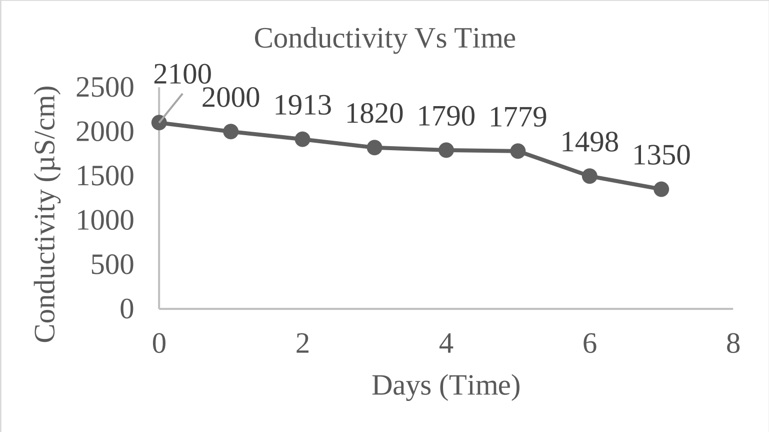

Figure 7. Variation of Conductivity (µS/cm) with respect to Time (Days)

3.8. Generation of electricity: The generation of electricity was analysed by multimeter. Zinc anode and carbon cathode which were extracted from battery were placed in the reactor in such a way that the circuits were closed and the voltage was analysed using multimeter. The current produced can be stored and converted to future use. From the experiment, a maximum of 7.2V was obtained at the end of day 1. Thereafter, voltage generation was decreased due to decrease in impurities (Figure 8). The decreasing rate of current is due to purification of waste water.

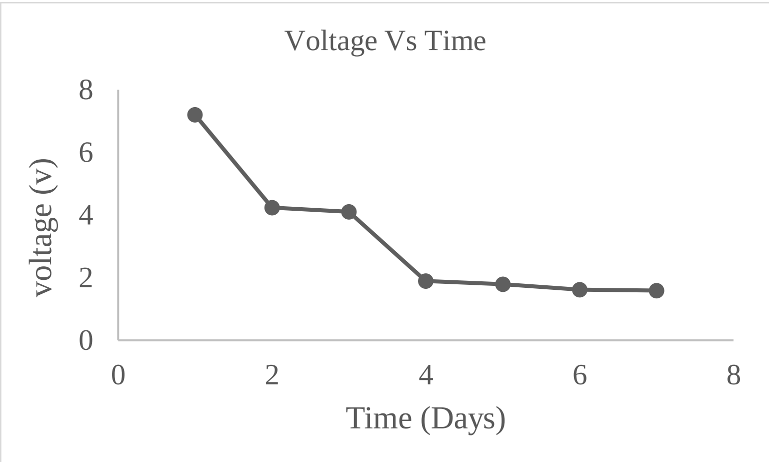

Figure 8. Variation of Voltage (V) with respect to Time (Days)

3.9. Physico-chemical characteristics of the treated effluent

After the combined treatment, the effluent was analysed for determining the physico-chemical characteristics in the laboratory. The findings are displayed in Table 2. Additionally, Conductivity obtained an optimum value of 1350µS/cm. It is clear that all the obtained values fall within the acceptable limits according to the BIS Guidelines for the quality of irrigation water, IS 11624 (1986) [8].

Table 2. Physico-chemical characteristics of industrial waste water after treatment

Sl. No.	Test conducted	After treatment	Limit as per BIS/Guidelines for quality of irrigation water IS 11624 (1986) [8] ACCEPTABLE LIMIT
1	pH	7.02	6.5-8.5
2	ALKALINITY (mg/L)	192	200
3	HARDNESS (mg/L)	157	200
4	BOD (mg/L)	97	100
5	COD (mg/L)	233	250

4.CONCLUSION

The integrated system of a constructed wetland coupled with a biofuel cell integrates the two technologies to treat wastewater and produce bioenergy simultaneously. Furthermore, plant biomass enhances the removal efficiency of dissolved nutrients and heavy metals through absorption, thus playing an essential role in wastewater treatment. Water hyacinth deserves special mention due to its extreme efficiency in this regard, growing in wetland environment, thus making it a viable option for decontaminating water with heavy metals. The analysis involved daily measurements of voltage generated as well as assessments of water purification effectiveness. The sample recorded a pH of 7.02, which is within the acceptable limit of 6.5 to 8.5. Alkalinity of treated water was found to be 192 mg/L, which is below the permissible limit of 200 mg/L. Treated effluent was clear, transparent, and odourless. Total hardness obtained a value of 157 mg/L that come under the permissible limit of 200 mg/L. BOD was recorded at a value of 97 mg/L and which falls in the acceptable limit of 100 mg/L. COD was observed as 233 mg/L, which is below the acceptable limit of 250 mg/L. Furthermore, conductivity was recorded at 1350 µS/cm. Electricity generation was monitored with a multimeter and observed to attain a maximum value of 7.2 V. The reduction in alkalinity, hardness, BOD, COD, and conductivity results from the purification of wastewater. A biofuel cell combined with a constructed wetland allows treated wastewater to be used for gardening and irrigation because of the absence of undesirable odours. The economic advantage of this treatment lies in the decrease in operation costs and energy consumption, which can also contribute towards reducing the release of effluents containing high organic loads.

CONFLICT-OF-INTEREST STATEMENT

The authors declare no conflicts of interest related to this research.

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